FPGA implementation of Neural Network controller for a Solar Energy Integration

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ABSTRACT

Renewable energies remain the main response to curb global warming. However, there is still a long way to go to achieve total renewable energy consumption. To achieve this, the artificial neural network (ANN) approach, which is an artificial intelligence (AI) model, is an asset to consider. This paper aims to improve the activation function an existing Recurrent Neural Network (RNN) to minimize the losses in solar energy generated from the solar panel during its integration into the power grid. By reducing the loss, the production renewable energy increases. The RNN is designed in VDHL language and embedded on the Field Programmable Gate Array (FPGA) board for implementation. With a quantitative approach, data collected from the solar panel are converted in 32 bits floating-point. The NN is trained to reduced loss of the input data. The reinforcement attribute of the RNN track errors in the forward feeding of neurons (nodes) and create adjustments on the output. In summary, the energy lost with the designed artificial neural network controller is significantly lower compared to the standard solar controller. This study demonstrated that highly optimization of digital and analog devices can be achieved by designing circuit based on the approach of artificial.

INTRODUCTION

Artificial Neural network (ANN) was inspired by the biological neural networks in the human brain.

The activating function could be considered as the neurotransmitter of the artificial neural network. This research improves the activation function a recurrent neural network by implementing five equivalent algebraic expressions of hyperbolic tangent (tanh) to determine which could deliver more accuracy and less clock latency. There is a variety of activation functions. The choice of usage depends on the characteristics of the ANN to build. In the case of this research, the choice of the hyperbolic tangent was made because it is nonlinear and bidirectional. The input data of RNN are the voltage generated by the solar panel and can be either positive and negative. Tanh values range between -1 and 1 and its slope is more stipend.

MATERIALS & METHODS

- FPGA board Cyclone IV EP4GX150DF31C7N
- Solar panel
- Quartus Prime 17.1 -Lite Edition

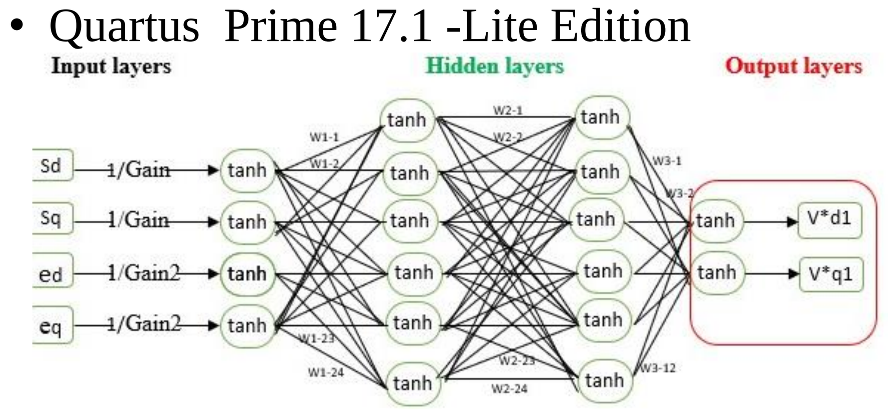

Figure 1: Neural network design with 2 hidden layers of 6 nodes each and 2 output nodes

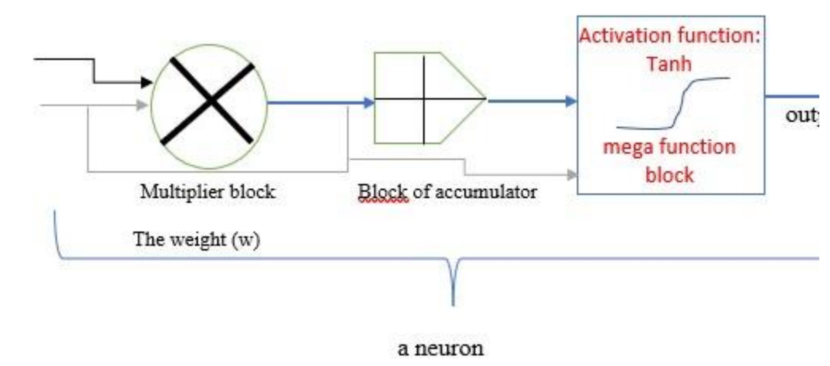

Figure 2 : Artificial neuron schematic design

❖ **Designing of four equivalent of models of tanh for comparison of time of execution**

The first model of tanh :	The second equivalent model of tanh:	The Third equivalent model :
$\tanh(x) = \dfrac{e^{2x}-1}{e^{2x}+1}$	$\dfrac{1}{1/x + \dfrac{1}{3/x + \dfrac{1}{5/x + \dfrac{1}{7/x + \dfrac{1}{9/x + \dfrac{1}{11/x + \dots}}}}}}$	$\dfrac{x}{1 + \dfrac{x^2}{3 + \dfrac{x^2}{5 + \dfrac{x^2}{7 + \dfrac{x^2}{9 + \dfrac{x^2}{11 + \dfrac{x^2}{13}}}}}}}$
Fourth eauivalent model of tanh: $\dfrac{x^7 + 378x^5 + 17325x^3 + 135135x}{28x^6 + 3150x^4 + 62370x^2 + 135135}$	**Fiith equivalent model of tanh :** $\tanh(x) = a(x) / b(x)$; $a(x) = (((x^2 + 378)x^2 + 17325)x^2 + 135135)x$; $b(x) = ((28x^2 + 3150)x^2 + 62370)x^2 + 135135$	

Table 1: Five algebraic equivalent expressions of hyperbolic tangent function

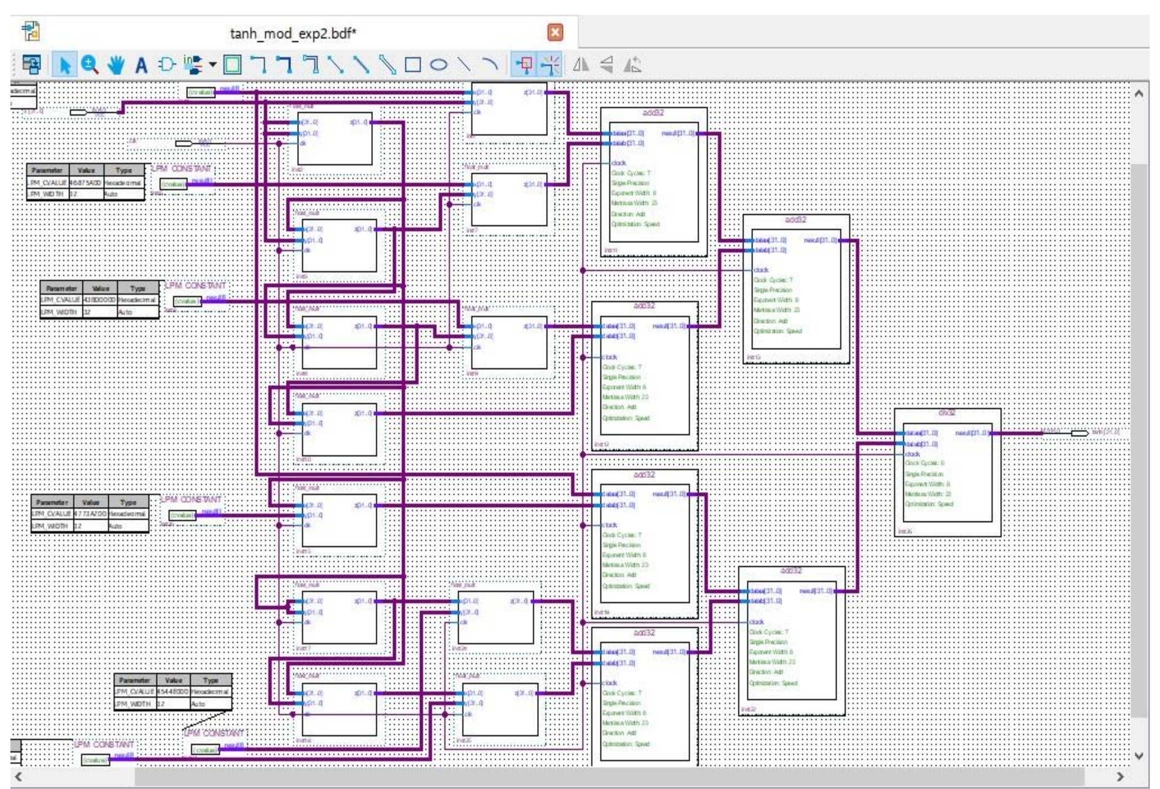

Figure 3: Schematic of the fourth model of tanh function.

RESULTS

- As a result, five models of the tanh function delivered the same results.
- The model 4 executes faster than others with improves clock latency.

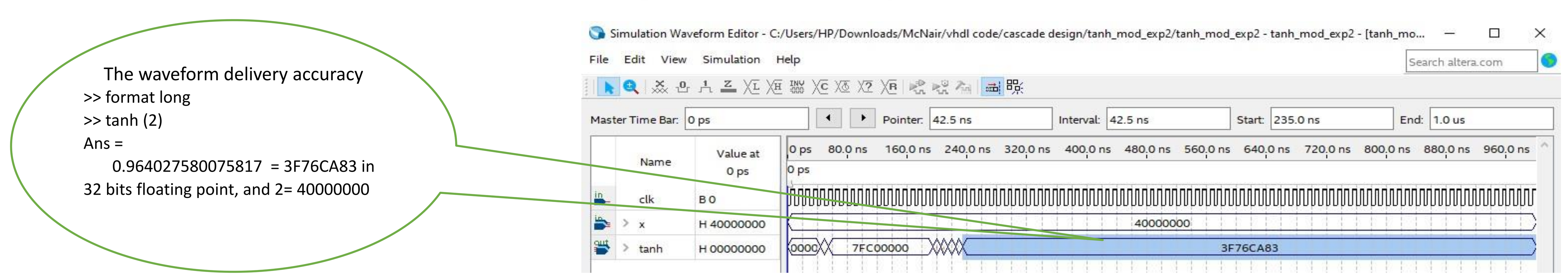

Figure 4 : waveform of timing diagram for model 4

- The research identified the model 4 as the faster for this specific study.
- The research has not concluded yet whether this model of hyperbolic tangent should be considered as the fastest for any digital circuit.

	Total registers	Block memory bits	PSP block	Time of Compilation	Pin number
Model 1	2,507	4,851/12,492,800 (<1%)	18/342 (5%)	9.22 minutes	65/480 (14%)
Model 2	6,415	55,2679/12,492,800 (<1%)	72/342 (21%)	11.25 minutes	65/480 (14%)
Model 3	3,926	27,666/12,492,800 (<1%)	43/342 (12.5%)	12.5 minutes	65/480 (14%)
Model 4	2,557	4,608/12,492,800 (<1%)	18/342 (5%)	8.4 minutes	65/480 (14%)
Model 5	2,705	4,608/12,492,800 (<1%)	13/342 (3%)	10 minutes	65/480 (14%)

Tables 2 : Performance chart of the five equivalent algebraic expressions of tanh

DISCUSSION

- The five equivalent tanh functions were designed for simulation on FPGA board Cyclone IV EP4GX150DF31C7N, to improve the performance of an ANN and to obtain the accurate output value of the digital circuit.
- The simplification of the of the ANN activation function in algebraic form eased its implementation on an FPGA board.
- Duration for building neural network was not sufficient, as a result, the research was held partly by PHD student.
- Using the 32-bit floating point data type provides accuracy results but remains difficult to implement because it is not synthesizable.
- For an efficiency in a future study, it would be better to use a large FPGA board.
- Several tests of this comparison need to be performed on different FPGA boards to confirm the finding of this research.

CONCLUSION

- By comparing five equivalent functions of the hyperbolic tangent, it turned out that the model four takes less memory size on the board, has faster compilation and has improved the clock latency.
- The choice of the activation function is the key element to define the training of the neural network.
- In the digital circuit, the implementation of a trigonometric or exponential function or any complicated function can be done by replacing it with an equivalent algebraic expression.

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